Pointing Alignment by
Orthogonal Phase-Lock Feedback Loops

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Abstract

Orthogonally acting phase-locked loops operating at distinct, well-separated dither frequencies are used to automatically align (maximize output power) an argon ion pump laser, its pointing into a ring dye laser, and optimize a dye laser beam coupling into a single mode fiber of 4 micron core diameter. Such a system of feedback loops or combination of them is an ATOM (Alignment Through Orthogonal Maxima).

Introduction

Fine alignment of an optical system is in general nontrivial when there is no information on which way to turn an alignment knob. When manually peaking up a system, an operator generally makes a small perturbation and monitors the result. After several perturbations a trend is observed and the desired quantity (output power, beam pointing, etc.) can then be optimized.

This operation may be performed automatically by making small periodic perturbations of the system alignment and monitoring the derivative of the desired quantity due to the perturbation [1,2]. A synchronous detection scheme can detect a component that is in phase with the perturbation providing a measure of the alignment error. The phase signal is then arranged to drive a motor that minimizes the phase signal and also maximizes the desired quantity. Such a detection scheme is readily implemented using a lock-in amplifier.

A single desired quantity may be dependent upon several alignment variables. In most cases each of these variables may be automatically adjusted independently (orthogonal) of the next. The alignment procedure is to dither each variable at different frequency and detect each phase signal using a lock-in amplifier. Each lock-in is adjusted to detect a specific frequency corresponding to the desired alignment variable. The output of the lock-in is then used to drive a motorized micrometer which minimize the phase signal while maximizing the desired quantity.

We wanted to maximize dye laser light coupling into a 4 micron fiber quickly (less than 15 minutes) and keep it aligned automatically. A problem occurs because the argon laser power drifts, and the beam pointing wanders as it heats up. This affects the dye laser output power. The dye laser is also susceptible to temperature changes which can alter its pointing into the fiber. We thus set out to automatically align this system of lasers and their pointings.

We demonstrated systems of feedback loops which peaked the alignment of an Argon laser prism wavelength selector, controlled the argon laser beam pointing onto the jet stream of a ring dye laser maximizing the dye laser output and then feedback aligned the dye laser beam for maximum coupling into a 4 micron core diameter fiber. Each of the feedback loops uses the same type of lock-in amp and motorized micrometers. The dithering of each variable is done with PZT tipped mirror (gives an angular dither), resonant tipping of glass plates, or resonant tipping of parallel mirrors (both giving displacement dither without angular dither).

Each individual system has been tested. The combined systems are under construction.

Each systems setup and feedback loop required is described illustrating the general procedure for implementing Alignment Through Orthogonal Maxima (ATOM).

General approach to implementing ATOM

In order to produce a phase signal from a system requiring alignment, one must move part of that system and monitor the parameter of interest. In most optical systems it's necessary to maximize light throughput. The light throughput will contain a phase signal as the system's mode volume is dithered past a limiting aperture. The dithering of the mode volume can take place at many different frequencies, one for each alignment parameter. A tuned filter (lock-in amplifier) can then single out one of the dither frequency avoiding crosstalk between the variables being aligned in a system of feedback loops. Since each alignment parameter has its own unique frequency it also has its own unique phase signal

that when applied in a positive feedback loop will minimize the phase signal and maximize the system throughput for that variable.

In figure 1. a scanner periodically perturbs the alignment by dithering the light mode across a limiting aperture. The light transmitted through the aperture contains a low level AC component that is phase detected with a lock-in. A level detector converts the lock-in voltage (see Figure 2.) to a clipped voltage for constant velocity motor control. To avoid alignment runaway (fail safe feature) the intensity level is monitored and enables the motor drive only when the intensity is above a preset threshold. The feedback voltages drive the motor which minimize the phase signal thereby maximizing the light through the aperture.
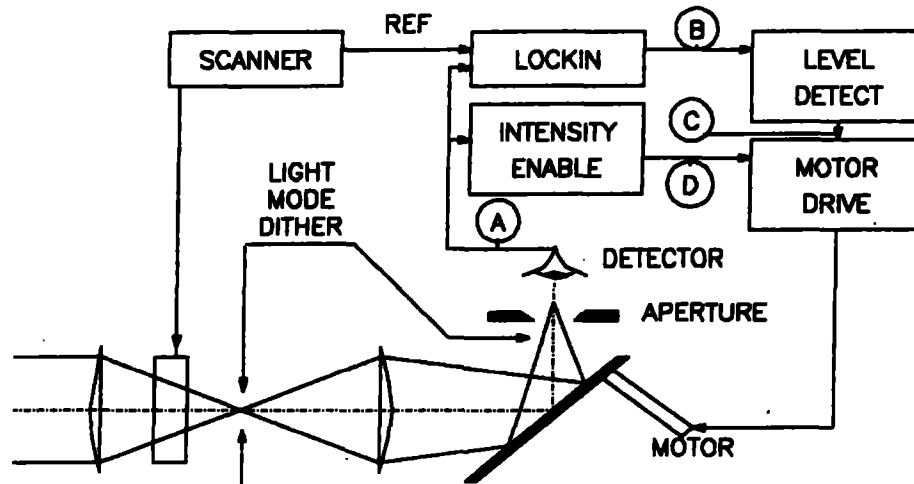

Figure 1. Block diagram of a feedback loop using a lock-in. REF is the phase reference to the lock-in from the scanner. The symbols A, B, C, D, are voltage signals plotted in figure 2.
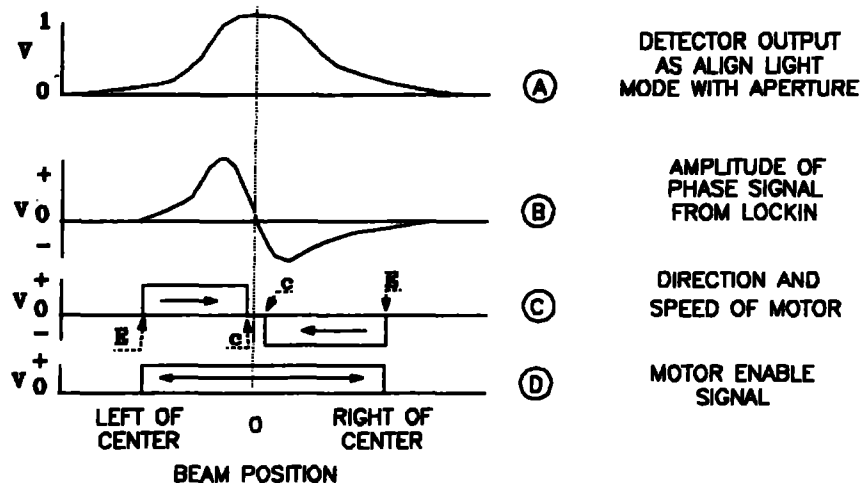

Figure 2. Voltage signals V at various points in the feedback loop as the light mode is scanned across the aperture. An inactive zone in the control loop response, shown between c improves overall stability and motor lifetime by allowing a small drift from optimum before correcting the alignment. The level setting at E determines when the system will be disabled due to a loss of alignment.

ATOM applied to Argon laser prism and mirror

When cold starting a Spectra Physics Argon ion laser Model #SP171 containing a prism for wavelength selectivity it may take 1/2 to 1 hour of running time for the prism to heat up in order for the laser to resume proper alignment hence maximum power output. This long time delay may be eliminated if the prism is feedback loop aligned. To do this the laser cavity mode is dithered past the plasma bore (the systems limiting aperture) and phase detection

(EG&G PAR Model 1501 Lock-in amplifiers) of the lasers output power is used to feedback loop align the prism end mirror, see Figure 3.. We mounted the wavelength selective end mirror (prism coupler) in a Burleigh Star Gimbal mount and dither the X (at frequency F1) and Y (at frequency F2) axis of the mirror mount holding the prism coupler with PZT pushers. There frequency of operation was carefully chosen to avoid mechanical resonances in the Burleigh mirror mount. These resonance can be the source of a phase shift in the dither of the laser mode as the mechanical stress and temperature change. This could change the sign of the phase signal out of the lock-in and drive the system out of alignment. The laser output power was phase detected using two lock-in amp each referenced to one of the dither frequency. The lock-in outputs drive X or Y motorized micrometers (Oriel Model 18009 Motor-Mikes) on the Burleigh mount, maintaining optimum alignment as the prism heats up. At one preset alignment and without feedback the Argon laser output power drifted to 66% of its full power compared to a drift to 87% of its full power when feedback was applied. This single component was not the only element needing adjustment (for this particular laser alignment) and further ATOM systems on other elements could bring the output power closer to optimum.
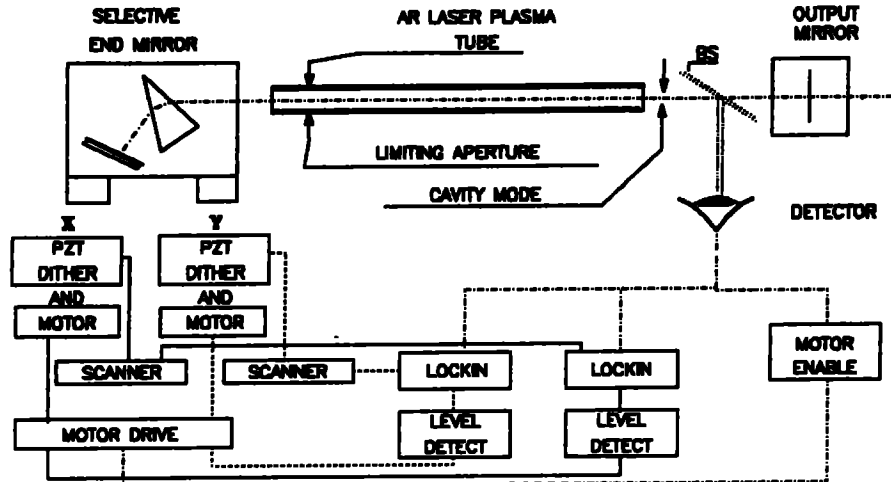

Figure 3. Lock-in feedback loop used to align the prism end mirror of an argon laser. It holds the Argon laser power maximized as the prism heats up.
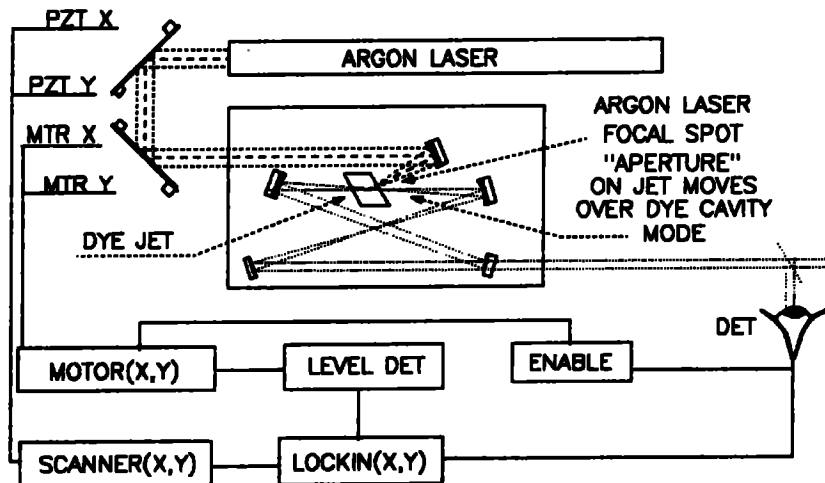
Figure 4. Shows the lock-in arrangement used to align an argon laser beam pointing into the jet stream and dye laser mode volume. It holds the dye laser power maximized as the argon laser pointing drifts during heat up.

Atom of the argon laser on the dye laser jet stream

As the argon laser heats up and its tuning prism is aligned the argon laser beam pointing wanders over the dye laser mode volume in the dye jet stream which effects the dye laser output. The pointing drift was eliminated by locking the argon laser pointing to maximize

the dye laser output. The phase dither was placed on the argon laser beam pumping the dye laser. It could be done by dithering a mirror directing the argon laser beam onto the jet stream or by dithering a focal spot using parallel mirrors or a window. Again PZT pushers supply the light mode angular dither past a limiting aperture, see Figure 4., There frequency must be different from F1 and F2 used on the argon laser prism alignment (since the dye laser power may contain F1 and or F2 should the argon laser misalign) and also must avoid mechanical resonances in the turning mirror mount. The motor aligning the laser beam is mounted on a separate mirror mount for convenience. The aperture in this case is the mode area at the dye jet stream that the dye laser cavity can support. Since the dye laser cavity can support many transverse modes it becomes necessary to have the dye laser operating in its proper spatial mode before the feedback loop is turned on, otherwise the loop will find the first mode it starts on and will hold that alignment.

When the dye laser was properly aligned it supported a Gaussian like spatial mode as the Argon laser spot was moved about the dye laser mode volume. In this case cold starting the Argon laser and waiting for it to warm up produce dye laser power fluctuations of 100%. With the Argon laser prism end mirror ATOM activated the dye laser would start at a low power enabling its ATOM of the argon laser pointing to maximize the dye laser output.

Spatial mode discrimination is possible at the detector monitoring the phase signal if an aperture is placed before the detector such to allow only the proper spatial mode to reach the detector.

ATOM of the dye laser coupling into a 4 micron fiber

The dye laser beam pointing wanders as the dye laser is aligned, its beam directing optics heat up and the room temperature changes. A phase lock feedback loop corrected thermal drifts.

Coarse alignment is done by manually monitoring in reflection the centering of each element in the laser beam while the beam axis is maintained on the fiber. The fine alignment into the fiber is done with a mirror pointing the collimated beam through a microscope objective lens, figure 6.
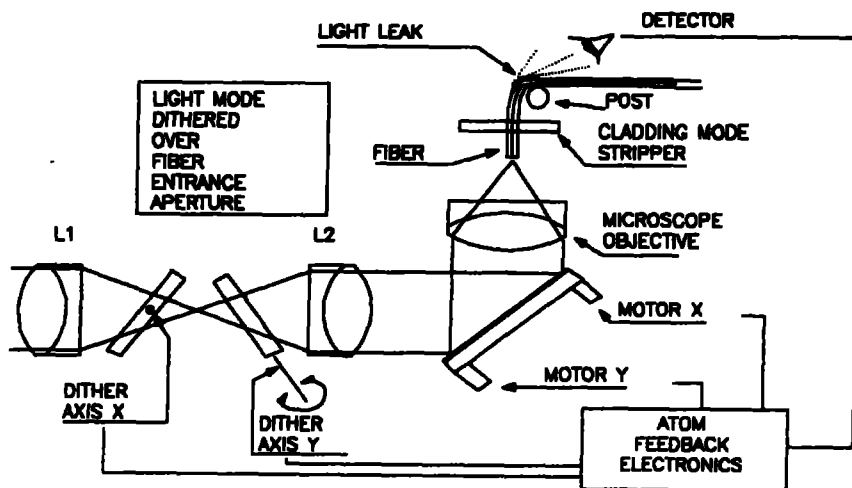

Figure 5. Dither axis X is out of the page, Dither axis Y is in the plane of the page. Each glass plate is mounted at Brewsters angle. The cladding mode stripper was rubber compressed around the fiber cladding. The fiber was bent around a post to allow light leaking from the core into the cladding. The cladding mode was then scattered out of the cladding with scotch tape on the outside fiber radius about the post and served as a power monitor inside the fiber core. The mirror directing light into the microscope objective was used to feedback loop align the laser into the fiber once all optical elements were centered. The ATOM feedback electronics is composed of the scanners to dither the glass plate, lock-in for X and Y axis phase monitoring, voltage clippers on the lock-in output voltage for constant velocity motor control, voltage clipper on the detector signal which enables the motor drivers and motor drivers.

To create a phase lock-loop on the dye laser light in the fiber core requires a dither of the dye laser beam focal spot over the fiber core while phase monitoring with a lock-in the light in the fiber. The dither along X axis at F5 = 10 KHZ and along Y axis at F6 = 16 KHZ was done with glass plates at Brewsters angle, Figure 6. One plate dithered perpendicular to

the Brewster angle plane and the other parallel to Brewster angle plane. The glass plates create beam motion parallel to the beam axis thus maintaining constant dither amplitude along the beam. This allows ATOM of many separate fibers or other systems using the F5 and F6 phase references. The light in the fiber core was monitored by bending it around a post allowing a light leak from core to cladding where scotch tape on the cladding scattered the cladding mode into a detector. Just before this light leak is a cladding mode stripper formed by compressing rubber on the fiber cladding. This helps avoid ATOM into a cladding mode.

With ATOM of the dye laser beam into the fiber it became easier to manually focus since the X and Y axis were automatically aligned. Over a one day period of time the typical power fluctuations of the dye light into the fiber were 30% of maximum without feedback. Generally the required adjustments occurred from room temperature changes as the system heated up.

Dither parallel to a beam axis using a glass plate

A glass plate can be used to produce dither parallel to a beam axis at high frequencies. Small 3 x 4 x 1 mm glass plate are mounted on torsion bar resonant scanners (American Time Products series L). They can reach frequencies of 16 KHZ and come supplied with reference frequency for phase locking a lock-in. There small window size (rather than mirrors) requires focusing through them. Two resonant plates are needed to dither each axis of a beam which will be aligned. One mounted at Brewsters angle is angle dithered perpendicular to the plane of incidence, the other mounted also at Brewsters angle is dithered in the plane of incidence, each at a different frequency.
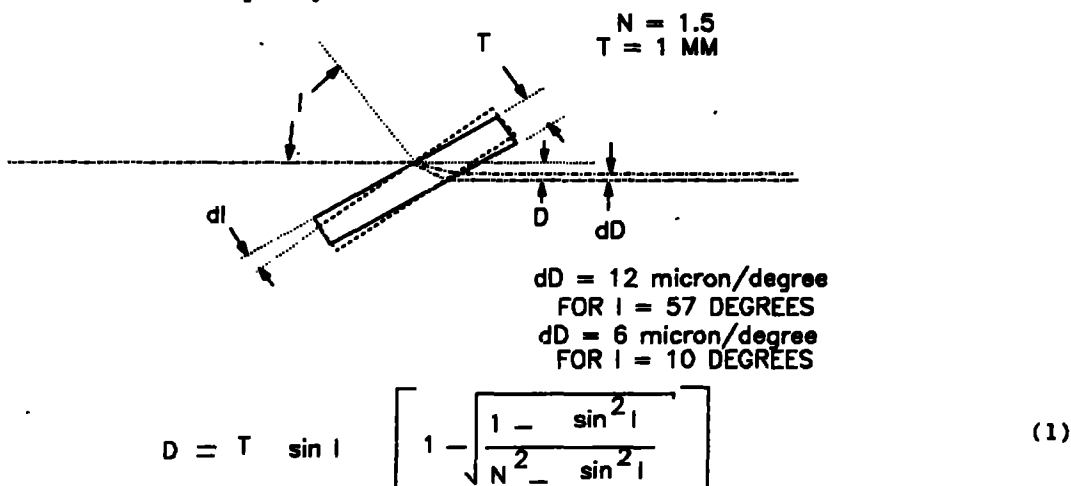

$$N = 1.5$$
$$T = 1 \text{ MM}$$

$$dD = 12 \text{ micron/degree}$$
$$\text{FOR I} = 57 \text{ DEGREES}$$
$$dD = 6 \text{ micron/degree}$$
$$\text{FOR I} = 10 \text{ DEGREES}$$

$$D = T \ \sin I \left[1 - \sqrt{\frac{1 - \sin^2 I}{N^2 - \sin^2 I}} \right] \tag{1}$$

Figure 6. Shows beam displacement dD with angular tip dI at an angle of incidence of I.

Conclusion

It is possible to automatically optimize the alignment of complex systems by dithering each adjustable parameter. The required uniqueness in alignment of each maxima achieved through differing frequencies. We have shown how to use lock-in and mode volume dither past a limiting aperture to form a positive feedback loop unique in frequency hence independent of other variables trying to maximize the same parameter. We canceled thermal drift of an argon laser prism end mirror, stabilized the argon pointing into a dye laser mode volume in a dye jet stream and optimized the dye laser coupling into a 4 micron core diameter fiber.

Acknowledgements

References

(1) Edye, T., Schwab, PH., Roussel, J. P., Parriaux, O., and Bugger, A., "Automatic alignment station for single or multimode optical fibers," SPIE., Vol. 483, pp. 65-69. 1984.

(2) Edye, T., Schwab, PH., Roussel, J. P., Parriaux, O., "Automatic assembling station for guided optics components," SPIE., Vol. 483, pp. 70-75. 1984.

Dither parallel to a beam axis using parallel mirrors

Two parallel mirrors mounted parallel together Figure 6. can be tipped to give displacement without angular change. The mirror arrangement is preferred over the window when aberrations are troublesome.
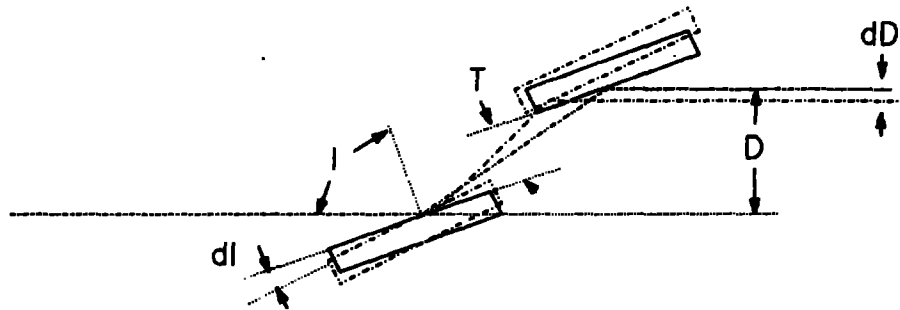
$$dD = \frac{2T}{COS\ I} \left[1 + 3\ SIN^2\ I \right]\ dI \qquad (2)$$

Figure 7. Shows beam displacement dD with angular tip dI for parallel tipped mirrors.